

.....

The Evolution of Intermediate Driven Belt Conveyor Technology

E.A. "Bud" Viren* and Mark A. Alspaugh*

The driving force behind most advances in technology is need. In the early 1980s, underground coal miners in the USA wanted to build longer conveyors to handle larger capacities but continue to use fabric reinforced belting with mechanical fasteners. Conveyors with intermediate drives were certainly the answer but achieving reliable designs required a significant learning curve. Basic design methodologies had to evolve including advanced simulation of starting and stopping along with complex control techniques and logic. Some components also evolved as specific performance requirements changed. Today, in addition to underground mining, the technology has been used extensively in the tunneling industry where the need is for control of belt tensions to negotiate tight horizontal curves. Even though intermediate drives are not used extensively on the surface yet, the lessons learned will find their way to long overland surface conveyance where smaller components are more available and reliable, and often with less capital cost. This paper will document the evolution of intermediate drive technology over the last 30 years and will show examples of its current use.

INTRODUCTION

The idea of distributing power in multiple locations on a belt conveyor has been around for a long time. The first application in the USA was installed by Continental Conveyor & Equipment Co. at Kaiser Coal in 1974. This was the first of two rubber tire driven intermediate drive installations. The second, at Brewster Phosphates, was 4,426 m in length and included eleven 150-kW booster drives.¹ In 1978 in Germany, an incline conveyor 720 m in length with 170 m of rise carrying 950 tonnes/h of coal was installed using a 4 × 80 kW main drive and 3 × 80 kW belt-on-belt intermediate drive.² It was shortly thereafter that underground coal mining began consolidating and longwall mines began to realize tremendous growth in output. Mining equipment efficiencies and capabilities improved dramatically. Miners were looking for ways to increase the lengths of panels in order to decrease the percentage of idle time needed to move the large mining equipment from panel to panel.

When panel lengths were increased, conveyance concerns began to appear. The power and belt strengths needed for these lengths approaching 4–5 km were much greater than had ever been used underground before. Problems included making room for the large size of high power drives as well as being able to handle and move them around. And, although belting technology could

handle the increased strength requirements, it meant moving to steel reinforced belting that was much heavier and harder to handle and, more importantly, required vulcanized splicing. Since longwall panel conveyors are constantly advancing and retreating (getting longer and shorter), miners are always adding or removing rolls of belting from the system. Moreover, since vulcanized splicing takes several times longer to facilitate, lost production time due to belt moves over the course of a complete panel during development and mining would be extreme.

Although the benefits of distributing power at various intermediate locations along a conveyor had been known for many years and attempted a few times, the concept was still uncertain. At this point the need surpassed the risk, and the application of intermediate drives to limit belt tensions and allow the use of fabric belting on long center applications was actively pursued.

Today, intermediate drive technology is very well accepted and widely used in underground coal mining. Many mines around the world have incorporated it into their current and future mine plans to increase the efficiency of their overall mining operations. A related industry, tunneling (Figure 1), has also adopted the technology with gusto and taken it to even higher levels of complexity and sophistication. Although aboveground

* Overland Conveyor Co., Inc., Carlisle, Wyo.

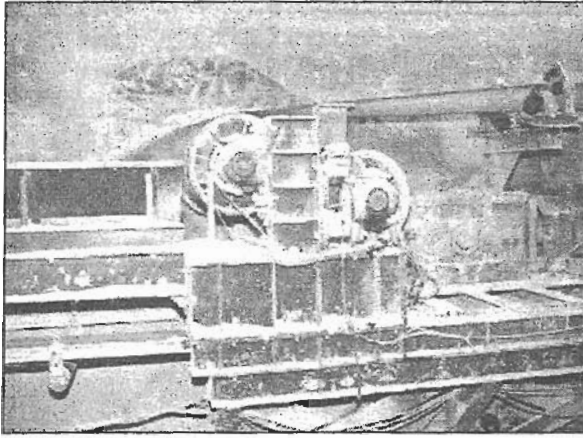


FIGURE 1 Dallas area rapid transit project (Courtesy of Continental Conveyor)



FIGURE 2 Seven Oaks Dam/CBPO (Courtesy of Continental Conveyor)

overland conveyors have not extensively used this technology to date (Figure 2), applications are now starting to exceed the limits of even steel reinforced belting, and intermediate drives will find their way into the light as future needs arise.

THE BENEFITS

The tension diagram in Figure 3 shows the simple principal and most significant benefit of intermediate belt conveyor drives. This flat, head-driven conveyor has a simple belt tension distribution as shown in black (single head drive). Although the average belt tension during each cycle is only about 40% of the peak value, all the belting must be sized for this maximum tension. The large drop in the black line (Single Head Drive) at the head pulley represents the total torque or power required to run the conveyor.

By splitting the power into two locations (red line—With 1 Intermediate Head Drive), the maximum belt tension is reduced by almost 40% while the total power requirement remains virtually the same. A belt with much lower strength rating can be utilized and smaller individual power units can be used. To extend the example further, a second intermediate drive is added (green line—With 2 Intermediate Head Drives) and the peak belt tension drops further. However, the benefit is less as the maximum tension is only reduced by 25%. Moreover, each additional drive produces exponentially decreasing benefits. This is reflected in the curve in Figure 4.

TYPES OF INTERMEDIATE DRIVES

Tires

As in any new technology, many things are tried and often discarded for various reasons. One of the initial trials to transmit power to the belt without wrapping around a flat pulley was through common automobile tires (Figure 5). Drive traction was provided by pressing tires above and below the belting.

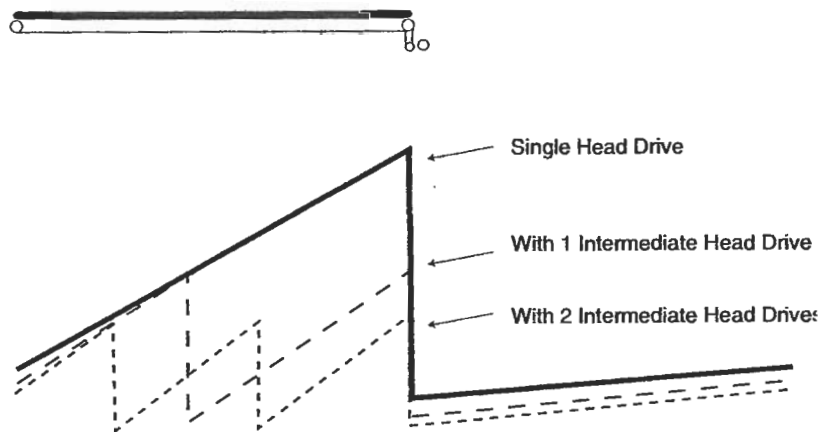


FIGURE 3 Belt tension diagram

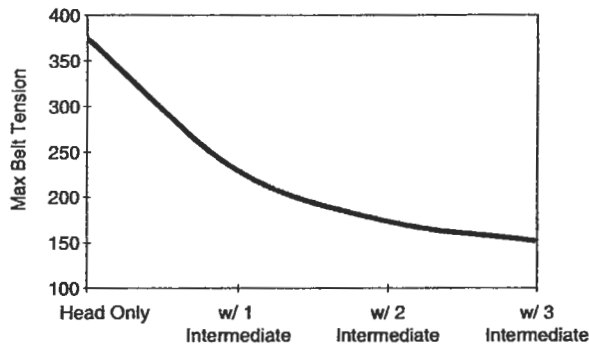


FIGURE 4 Maximum belt tensions versus number of drives

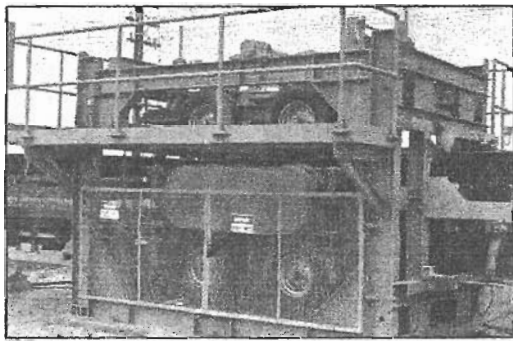


FIGURE 5

Linear (Belt-on-Belt)

Another arrangement that was more successful was called the belt-on-belt or linear drive (Figure 6). These linear drive arrangements simply consisted of small conveyors built inside the larger conveyor. Drive power was transmitted to the small belt through a traditional flat pulley, which transmitted torque to the larger conveyor through friction between the two belt surfaces. This scenario was particularly encouraged by the belt manufacturers as the elimination of transfer points was expected to greatly extend the belt wear life.

Several of these conveyors were installed in the mid- to late 1980s. The first significant application in the USA was at USX Mine 37 in Lynch, Kentucky. This equipment was installed in 1985. It was a mainline underground coal application with a 1,524-mm-wide belt, carrying 4,600 tph. It had a total of 2,238 kW installed power which included four belt-on-belt intermediate drives. Although this mine is no longer active and the conveyor system is gone, this is still one of the most impressive applications of the early technology.

The problems included the extra expense of the driving conveyor. It was common to provide one foot of driving belt length for every horsepower installed. Therefore, the above USX application had 4×200 m driving belts for a total of 1,600 m of extra belting, not to mention the many extra pulleys, take-ups, etc. In the initial 1978 German installation, the driving belt was 200 m long, which was 28% of the total conveying length. The second problem was discovered when it was later determined

that interactive torque control was necessary. There was no easy way to monitor what the drive needed to be doing based on material load.

Tripper

The industry gradually migrated in the late 1980s to the "tripper" drive configuration shown in Figure 7. When the industry went back to this conventional method of driving over a flat pulley, the technology became widely accepted and progressed rapidly. Methods of measuring belt tension to monitor material load and control torque were developed. The ease of installation and removal made by tripper drives quickly gained favor by the mines. In addition, the longwall could mine to within a few hundred feet of the tripper drive. The belt-on-belt technology often required that the intermediate drive be removed too soon. This resulted in a temporary underpower condition. In addition, it was quickly discovered that the "tripper" transfer was not nearly as hard on the belt as a conventional transfer between two conveyors as they are always in-line and the discharging belt speed and receiving belt speed must always be the same since they are the same belt. Spillage and cleanup also proved to be minimal.

Today, there are no belt-on-belt drives running in the USA and all new installations are as shown in Figure 7 or a variation of this "tripper" theme.

TORQUE CONTROL

Of course, every significant benefit comes with inherent negatives or risks. In the case of intermediate drives, the most significant risk is the added complexity of design and implementation. Distributing power along a flexible conveyor belt requires detailed attention to how the power is applied at each drive location relative to all the possible load variations that might exist. If too much power is applied at the wrong location, belt tensions can drop too low and drive slip or belt sag and material spillage can occur. If too little power is applied at one drive location, other drive locations may become overloaded and stall. Of course, this is of interest during normal running conditions but is especially critical during the transient condition of starting and stopping as belt tensions are fluctuating due to the inherent flexible nature of the belting. Since the ultimate goal is to use lower strength (low modulus) fabric belting on long center conveyors, dynamic concerns and potential problems are magnified.

In early intermediate drive applications, little thought was put into the control of drive torque. With single drive location conveyors used up to this point, torque control during acceleration was typical to control the acceleration ramp but no control was used after the conveyor was brought up to full speed. Although some smaller intermediate driven conveyors were successful without running torque control, it was soon concluded the complexity of most applications required torque control during running conditions. Many of the traditional acceleration torque control components in use at that time including wound rotor motors; reduced voltage starters and scope tube fluid couplings did not provide the ability or the accuracy necessary to properly control torque continuously.

Hydroviscous Clutch

One drive that did provide the necessary characteristics was the hydroviscous clutching device such as the Dodge

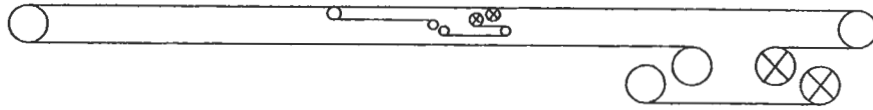


FIGURE 6

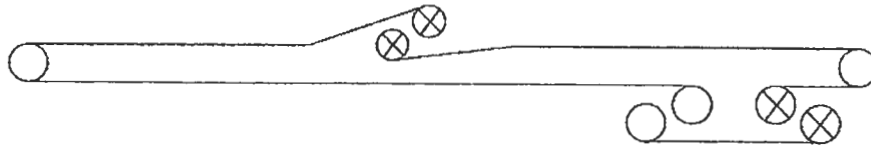
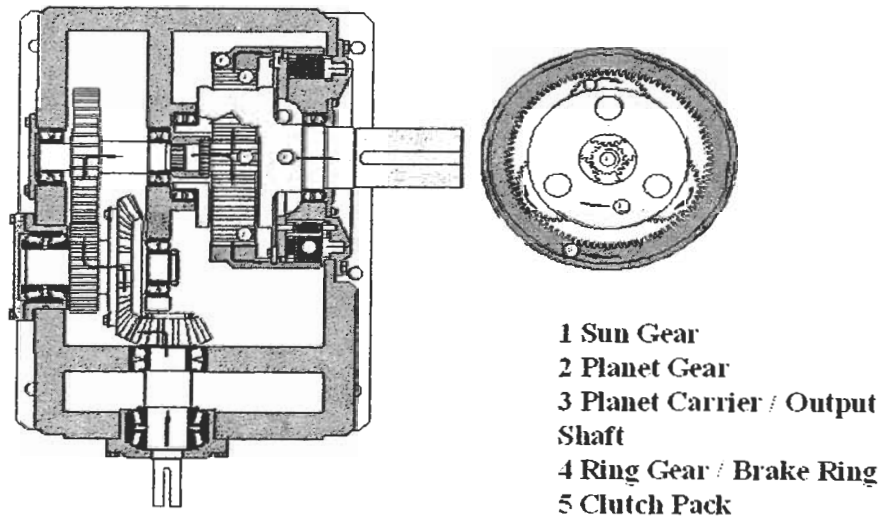


FIGURE 7



- 1 Sun Gear
- 2 Planet Gear
- 3 Planet Carrier / Output Shaft
- 4 Ring Gear / Brake Ring
- 5 Clutch Pack

FIGURE 8 Dodge CST

CST (Figure 8). Although it was traditional to vary the clutch pressure during acceleration and lock the clutch during running, it was found the clutch could be left in a constant slip state which provided the means to control torque at all times. And, since the clutch was on the low speed side of the reducer, the clutch provided adequate precision.

DC and VFD

Later, an old technology, DC drives, were brought back to belt conveying because of their inherent ability to provide precise torque control.³ DC drives were quite common for several years and are still in use today on many applications. But on new applications today, variable frequency drives (VFD) have replaced DC because of maintenance and cost issues while still providing excellent torque control.

Variable Fill Fluid Couplings

Intermediate drive technology and the need for precise torque control have helped change the belt conveying industry. Just as VFDs are quite common today in belt conveyance, fluid coupling manufacturer Voith devel-

oped a new TPKL product (Figure 9) due to the need for precise active torque control. Infinitely variable adjustment of the fill level (0%–100%) is possible. The speed of the conveyor can be varied by changing the fill or slip ratio. Load sharing is possible with any number of drives.

DYNAMIC ANALYSIS

Of course, having equipment that can provide the required performance is critical, but understanding what performance characteristics are required and developing the proper control logic is just as important. New design methodologies had to be developed to properly model critical component requirements including the belt, pulleys, and take-up. Traditional static analysis techniques as described in CEMA⁴ were generally adequate (with modification to allow distributed horsepower) for modeling running conditions, but the rigid body method employed to analyze starting and stopping was inadequate. The idea of analyzing conveyors as flexible systems (dynamic analysis) was first introduced in 1974 by Funke⁵ but was not yet widely used in the 1980s due to its complexity and cost. However, the lower stiffness of fabric belting and greater inherent elongation along

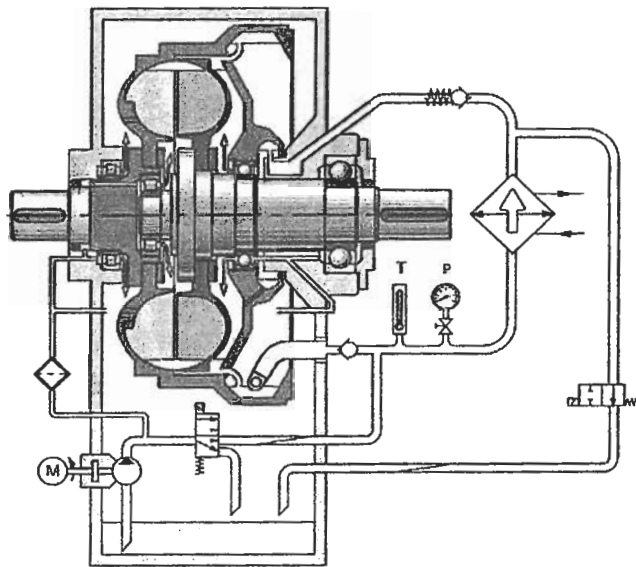


FIGURE 9 Voith TPKL

with the longer lengths employed with intermediate drives soon revealed significant transient tensions and the more advanced dynamic simulation techniques were soon employed.⁶ Dynamic analysis has proven invaluable in setting up complex starting control algorithms as well as defining more stringent and complex requirements of the take-up device and should be utilized on all intermediate drive applications (Figure 10).

TAKE-UP

Since intermediate drives have been used extensively in underground mining, mechanical take-ups in the form of hydraulic cylinders and mechanical sheaving were commonly employed. And since intermediate drives were mostly utilized on longwall panel conveyors, belt storage had to be incorporated into the take-ups (up to 450 m) making these units very large and complex (Figure 11). In addition to increased drive torque control requirements, intermediate driven conveyors also demanded increased performance from the take-up device in terms of reaction time, speed, and tension control. Hydraulic cylinders could no longer provide the performance required.

Significant work went into the development of "constant tension" hydraulic winch take-up devices and then to electric "flux vector" winches (Figure 12). These devices provided increased controllability and response time and could be equipped with load cell feedback mechanisms to constantly monitor and control belt tensions if required. This gave the conveyor designer increased flexibility to vary take-up tensions during starting or stopping and sometimes even during normal running operation.

UNDERGROUND COAL APPLICATIONS

Today, intermediate drives are readily accepted in underground coal mining around the world. A recent survey of the 50 USA longwall mines showed 60% were currently

using or would be using intermediate drives in the near future. A longwall panel with two trippers drives was recently installed in England and many have been employed in Australia. A sampling of current systems in operation around the USA is included in Table 1.

At MinExpo 2000 in Las Vegas, Nevada, P.K. Sollars, Maintenance Manager at RAG Twentymile Coal Co., presented the evolution of their belt conveyance system since the mine began longwall operations in 1989.⁷ Intermediate drives have been an integral part of their conveyance system since the beginning and many technology innovations have evolved at this mine. Two of the most impressive conveyors presented included the conveyor with the most attached power in the USA and a unique panel application utilizing intermediate regenerative drives and intermediate braking.

The 2 Main North Conveyor (Figure 13) at Twentymile Coal is 2,271 m in length with 268 m of lift. It is designed to carry 4,550 tph and has 5371 kW (16 motors) attached including the three tripper drives. The 9 Right panel conveyor (Figure 14) at Twentymile Coal was operated in 1995-96. It was 5,377 m in length and included a 159-m decline and 185-m incline. This profile included both very high power conditions and very high regenerative conditions. This was the first application of an intermediate braking station used in conjunction with a tail brake requiring very complex stopping control algorithms. This technology has since been extended to include multiple intermediate regenerative drives at Twentymile Coal as they continue to push the technology limits.

TUNNELING APPLICATIONS

Intermediate drive technology has been utilized in the international tunneling/construction industry for approximately 15 years. The majority of the larger tunneling applications are suited for this technology, due to tunnel diameter, tunnel length, and the amount of material to be conveyed/removed. Most applications

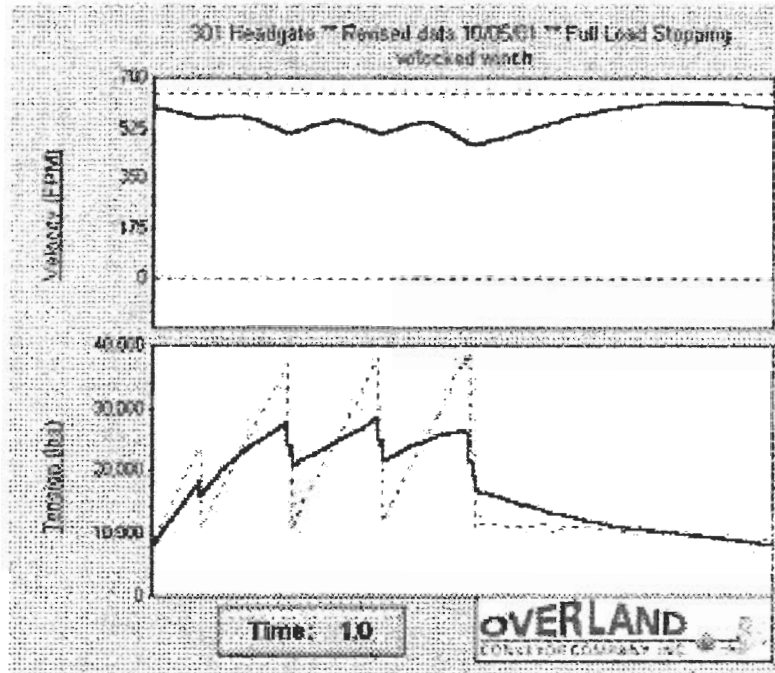


FIGURE 10

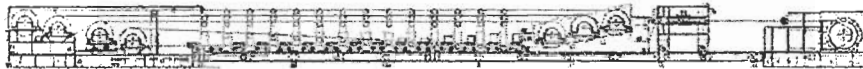


FIGURE 11

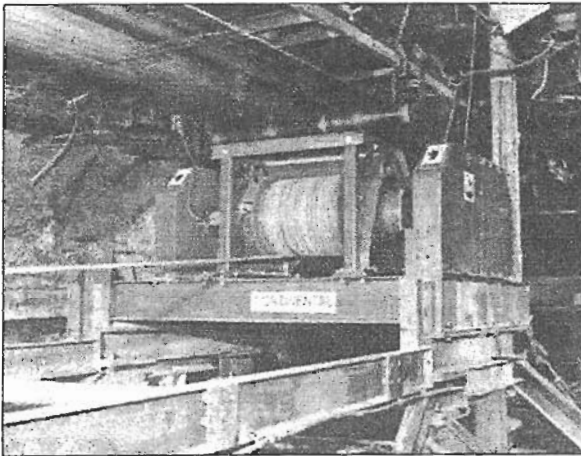


FIGURE 12

utilizing conveyors are in the range of 3,000 m to 20,000 m. However, the tonnage rate is low. Due to low tonnage requirements and size constraints, tunnel conveyors are relatively narrow and low-strength belts must be used to accommodate the narrow widths. Utilizing intermediate drives allows the contractor to locate a storage unit

outside on the surface and install all belting from one location throughout the project.

Horizontal curves are often required in tunnels and intermediate drives are often used as a method of maintaining low and more consistent belt tensions in these areas allowing conveyors to negotiate horizontal curves as small as 250 m. Single flights conveyors have been designed and operated with 10 trippers and up to 17 horizontal curves. A sampling of tunneling systems both past and present is shown in Table 2.

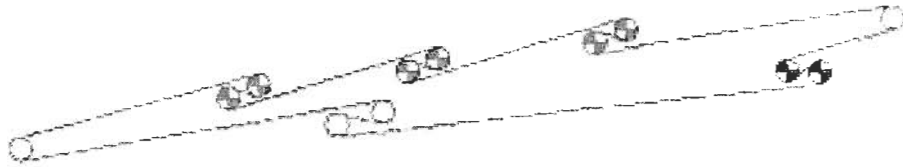
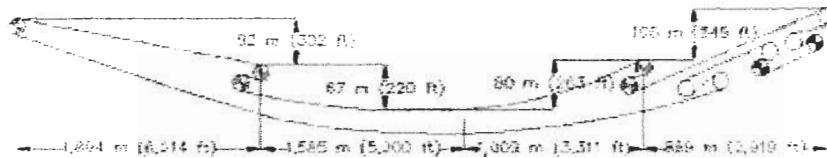
In May 1995, the US Department of Energy awarded The Conveyor Co. of Sibley, Iowa, the contract to build a conveyor to follow the tunnel-boring machine at the Yucca Mountain Nevada Nuclear Waste Depository (Figure 15). The conveyor included three horizontal curves turning a total of 208 degrees. Six intermediate drives (4 carry and 2 return) were incorporated to handle the 300-m horizontal radii. The conveyor successfully finished the project in April 1997.

CONCLUSIONS

The use of intermediate drives has successfully transitioned from a new idea to a mature proven technology. Over many years, many lessons have been learned and many obstacles have been overcome. The required precise drive torque characteristics have resulted in

TABLE 1 Sample of Intermediate driven conveyor in USA underground coal mines

Location	Width (mm)	Length (M)	Capacity (MTPH)	Installed Power (kW)	Intermediate Drives	Drive Type
Alabama	1,524	3,350	4,000	1,790	1	Hydroviscous Clutch
Colorado	1,524	2,271	4,000	5,371	3	CST
Colorado	1,800	5,377	5,000	1,940	2	CST
Illinois	1,350	4,268	2,200	1,194	1	VFD
Kentucky	1,524	3,658	3,500	2,685	3	DC
Pennsylvania	1,524	4,410	4,000	2,237	2	CST
Utah	1,524	5,091	3,200	2,984	2	VFD
West Virginia	1,524	6,097	3,500	3,357	4	DC


FIGURE 13

FIGURE 14
TABLE 2 Sample of Intermediate driven tunnel conveyors

Project/Location	Width (mm)	Length (M)	Capacity (MTPH)	Horizontal Curves	Minimum Radii	Installed Power (kW)	Intermediate Drives	Installation Completed
DART/USA	750	5,395	725	13	300	600	2	1994
TARP/USA	900	13,985	1,270	17	300	2,244	10	1996
Yucca/USA	900	7,900	1,000	3	300	969	6	1997
CTRL/UK-P240	800	2 × 4,700	800	3	2,500	480	1	2002
CTRL/UK-P250	800	2 × 5,300	800	3	2,500	640	2	2002
UTE Guadarrama North #3	900	13,377	1,150	2	7,000	1,120	3	2003
UTE Guadarrama North #4	900	15,000	1,150	2	7,000	1,280	3	2003
Barcelona Metro UTE Linea 9	1,000	8,390	1,500	6	280	1,600	9	2003

significant improvements in drive equipment technology as well as improved take-up design.

There are many ways to transport bulk material from one point to the next and no one technology is right for all applications. In surface conveying, the need to reduce belt tensions is not as significant as in underground applications, so intermediate drive technology has been utilized very seldom. However, conveying applications are continuing to get longer and intermediate drives

coupled with horizontal curves can provide more efficient solutions to many of today's bulk material transport needs. There is no doubt that intermediate drive technology should be and will be considered a viable option in surface overland conveyors in the future.

REFERENCES

- McGaha, J.R., and J.A. Dos Santos. 1997. Modern Continuous Haulage Systems and Equipment. *Bulk Solids Handling*. 17:3.

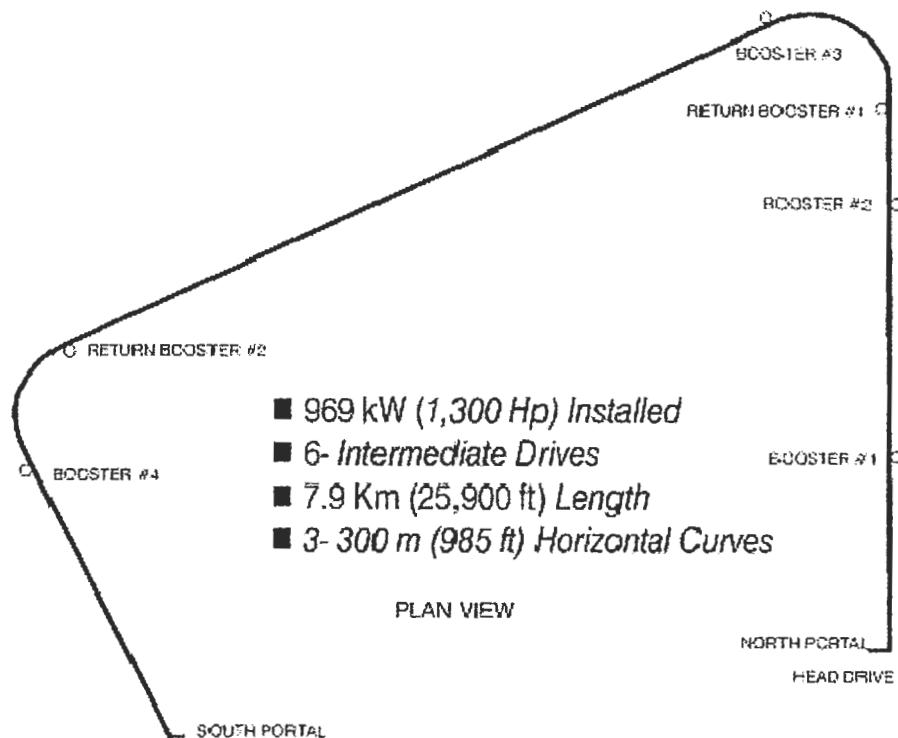


FIGURE 15

2. Bahke, Torsten. 1982. Dimensioning and Application of Belt Conveyors with Intermediate Drive (T-T System). *Bulk Solids Handling*. 2:1.
3. Alspaugh, M.A., and R.J. Wise. 1993. The Design and Operation of an Underground Conveyor Utilizing Intermediate Booster Drives with DC Motors and Controls. In *Conveyor Belt Engineering for the Coal and Mineral Mining Industries*. Littleton, Colo.: Society for Mining, Metallurgy and Exploration, Inc.
4. *Belt Conveyors for Bulk Materials*. 1999. Conveyor Equipment Manufacturers Association, 5th ed.
5. Funke, H. 1974. The Dynamic Stress of Conveyor Belt Systems During Starting and Stopping. *Braunkohle*. 26:3.
6. O'Donovan, E.J. 1993. Dynamic Analysis-Benefits for all Conveyors. In *Conveyor Belt Engineering for the Coal and Mineral Mining Industries*. Littleton, Colo.: Society for Mining, Metallurgy and Exploration, Inc.
7. Sollars, P.K., E.J. Brady, and M.A. Alspaugh. 2000. *Twentymile Coal Company's Underground Conveyance System*. Presented at MinExpo 2000, Las Vegas, Nev., September 2000.